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UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF ENTOMOLOGY

FOREST INSECT INVESTIGATIONS

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STUDIES IN THE BIOLOGICAL CONTROL

OF THE

WESTERN PINE BEETLE, DENDROCTONUS BREVICOMIS LEC.

by

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1930

Berkeley, California
November 30 1930

U. S. GOVERNMENT PRINTING OFFICE: 1928 J 76133

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Abstract

Studies in the biological control of the western pine beetle have been followed for the last three years on the Modoc National Forest of northeastern California. The method used is to fell and trim the limbs from the infested trees, leaving the trunk exposed to full sunlight, or as near to that condition as is possible in [illegible] field.

The purpose of the studies is to develop a method of control that will be reasonably effective on the summer generation of D. brevicomis and that will not result in the destruction of the beneficial predators.

Although satisfactory conclusions have not [illegible] reached in regard to all the points covered, the following include most of the results of the study to date:

Under the conditions prevailing on the area studied, an average reduction of between 40 and 50 per cent of the D. brevicomis broods results without apparent injury to the predators.

On the tops of the most favorably exposed logs a mortality of over 90 per cent of the broods occurred, and the mortality on the sides and bottom was considerably higher than in unexposed samples comparable with infested bark on trees left standing.

Both of the principal predators, N.lecontei and T.virescens var. chlorodia, are not only able to escape from conditions which prove fatal to the bark beetle, but they are also apparently able to withstand higher temperatures.

The method would be effective only in fairly open stands and in areas where the topography is fairly level or with few steep, northerly exposures. The method is apparently effective if the unfavorable exposures have slopes of not over 15 or 20 per cent. Little direct killing from high temperatures would occur where the shade on the exposed logs amounted to more than 15 or 20 per cent.

The effectiveness of the method could probably be increased by turning the logs half around after the brood on the top side had been largely killed; by dragging logs from heavily-shaded spots out into openings; and by sun-curing the infested bark from trees in which a good brood reduction could not be secured by the exposure method.

STUDIES IN THE BIOLOGICAL CONTROL
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Introduction

The need for some improvement in our present methods of control of the western pine beetle has been recognized for some time. The usual method—that of felling the trees and peeling and burning the infested bark—has too often proved ineffective in reducing the infestation, or if effective only temporarily so. Believing that one probable reason for these unsatisfactory results is the fact that in burning the infested bark all the beneficial predators are destroyed with the western pine beetle, a study of these predators was begun in 1922. These studies were continued as time permitted; and as a result of the knowledge of the habits of the predators gained by the study of their habits and life history, it was possible to start more definite experiments in biological control in 1928. During the last three years the aim has been to develop some new or supplementary method of control, by exposure instead of burning, which will kill a fair percentage of the D. brevicomis brood without injury to the predators[1].

The value of some method of control by biological means which would not result in injury to the beneficial predators and which would not endanger the forest with fire, would be especially great in areas of high timber values and recreational areas where maintenance control, including control work on the summer generation of the western pine beetle, is desirable.

The basis for the proposed method of biological control lies in the much greater motility of the predators, as compared to the western pine beetle, in the larval stage. This makes it possible for the predators to escape from conditions which prove fatal to the western pine beetle.

The treatment in this method of control consists in felling the infested trees in exposed situations and trimming the limbs so as to leave the trunk exposed to direct sunlight. High bark temperatures, unfavorable moisture conditions and the concentration of predators are depended on to reduce the western pine beetle broods without injury to the predators. The bark is not peeled, as in the other methods, but left intact on the trunk. It is obvious that this method is applicable only during periods of fairly high air temperatures. It is also limited to summer-generation trees, because it is only on these trees that the most important predator, Enoclerus lecontei Wolc., is abundant enough to be an important factor.

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[1] Little attention has been paid to the parasites in these studies, since it has been found that they are of little or no importance in the natural control of the western pine beetle.

Review of Earlier Studies

Study of the Natural Insect Enemies of the Western Pine Beetle

The first work on biological control of the western pine beetle was started in 1922 in connection with the Southern Oregon-Northern California Control Project. It was limited to the study of the relative importance of the natural insect enemies of the western pine beetle and to the study of the life history and habits of those found to be of most importance.

As a result of this work, which was continued until 1923, the following conclusions, having particular applicability to this paper, were reached:

1. Parasites are of only minor importance in the natural control of D.brevicomis;

2. The clerid, E.lecontei, is undoubtedly the most important natural insect enemy of the western pine beetle, although the ostomid, Temnochila virescens Fabr. var. chlorodia (Mann.), is also of considerable importance;

3. The clerid is most abundant on summer-generation trees, as many as 50 larvae being found in one square foot of bark infested with D.brevicomis;

4. The burning method of control should not be used on these summer-generation trees because of the abundance of predators on them;

5. Because many of the mature clerid larvae migrate to the base of the tree, control fires on winter-generation trees should be kept away from this part of the tree;

6. The mutility of the predaceous larvae and the migratory habit of the mature E.lecontei larvae suggest the possibility of reducing the broods of D.brevicomis appreciably during the summer, without injury to the predators, by felling infested trees and exposing the trunks. (For further details see 1923 report by Person (1).)

Biological Control Studies of 1928 and 1929

Following the study of the life history, habits and importance of the two principal predators of the western pine beetle, E.lecontei and T.virescens chlorodia, work was started in 1928 to determine the effect, on both the western pine beetle and its predators, of exposing infested logs to direct sunlight during the summer months. This work has been continued for the past three years.

In 1928 one infested tree was studied in considerable detail to determine the effect of different treatments on both the western pine beetle and its predators. Four logs from this tree were exposed under different conditions of shade and distance above the ground, and the effect determined for the top, bottom and two sides of all four logs. Six other infested trees were studied in less detail to obtain supplementary data. (See Person (2) for a more complete report on the season's work.)

The 1929 studies (Person (3)) were largely limited to the study of the temperatures found on the four quadrants of exposed logs and their relation to air temperatures. At the same time a study was made of the effect of temperatures on broods in different quadrants of one of the logs used in the temperature study, and additional data were obtained from three other trees on the effect of exposure in different situations on D.brevicomis and its associated predators.

As a result of the studies of 1928 and 1929 the following conclusions were reached:

1. Logs may be exposed under field conditions so that a fairly high percentage of the broods of D.brevicomis are killed without apparent injury to the important beneficial predators.

On the tops of logs mortality may amount to between 90 and 100 per cent under favorable conditions.

The mortality of D.brevicomis on the sides and bottom of exposed logs is evidently higher than in infested trees which are left standing, probably because of less favorable temperature and moisture conditions and the concentration of predators which are driven from the top of the log by high temperatures.

2. No evidence of injury to predators was found except in a single example which had an unusually hot exposure.

Clerid larvae are not only able to escape from unfavorable situations because of their motility, but are apparently able to withstand high temperatures which prove fatal to D.brevicomis.

3. This method of control is limited to use on summer-generation trees in areas with open stands and moderate or favorable (southerly) slopes.

It was also quite definitely shown that there is a concentration of predators on the sides of exposed logs, resulting from the migration of the clerids from the top of the log.

The relation between air temperature and bark temperature was worked out so that it is possible to predict the approximate brood mortality on the top of a fully-exposed log if the air temperature is known. (See Keen (4) for a report on similar work in southern Oregon.)

The 1930 Studies

Purpose

The biological control studies of 1928 and 1929 were continued in 1930 to check the conclusions reached in 1929 and to broaden the study by covering a range of conditions more nearly comparable to what might be encountered in a control project. Because of the amount of work involved in a detailed study of even one tree, it was not possible in 1928 or 1929 to study the effect of differences in amount of shade, stage of brood, exposure and slope, and other factors which would naturally affect the amount of brood mortality in the exposed trees. Neither was it possible in 1930, with the time and equipment available, to study enough trees to supply the basis for a statistical study of these factors. It was possible, however, to use enough trees to give an indication of the importance of a few of the factors. Nothing less than an experimental control project on a fairly large scale would be necessary for an adequate study of the influence of the different factors.

General Conditions

The field base, which was located near Willow Ranch during 1928 and 1929, was moved to Hackamore in June 1930, principally because of the need for a larger supply of infested trees than was available in the North Warners. The Happy Camp-Lava Bed area, in which Hackamore is advantageously located, is also much better suited to the biological control work than the Warners, because the topography is comparatively level and the stand is more open. Most of the area is a pure western yellow pine type, uneven-aged and fairly open. The sites are principally III and IV. The elevation varies between 4,000 and 5,000 feet over most of the area.

The infestation, which reached a high epidemic stage in 1927, declined until the 1930 loss was down close to normal for the area, with a volume loss of less than one per cent of the stand. Unfortunately for the purpose of this study there was no group infestation, and so we were not able to use a new method for determining the brood reduction of exposed trees in comparison with that for standing trees, as was planned.

A weather station was established at Hackamore, from which we obtained continuous records of temperature and humidity (see Fig. 1).

Selection of Trees

As this study has been limited to work on D.brevicomis and its two principal predators, considerable care was taken to select only trees which had fairly pure D.brevicomis infestation on the main part of the trunk. This necessitates the felling of a large number of trees because of the prevalence of mixed-brood trees (trees attacked by D.monticolae, Ips emarginatus, Melanophila gentilis and D.valens as well as by D.brevicomis), which could not always be distinguished from D.brevicomis trees by a basal examination. By examining a large number of trees

in different parts of the Happy Camp-Lava Bed area it was possible to select 12 trees which were fairly typical of the pure D.brevicomis brood trees. Seven of the trees used were located near the Pickering Portable Mill, three were either on or near the experimental marking plots in the vicinity of Flag Springs, and two were on the north slope of Timber Mountain.

Since in selecting the trees the primary consideration was to find trees with a good, even D.brevicomis attack over the main part of the trunk, it was not possible to make a selection according to exposure, slope, shade and other factors which affect the results of the exposure. While this failed to give us the range of conditions that we might have secured by a different selection, it was fortunate in that the trees used probably represented average conditions of shade, exposure and other site factors for D.brevicomis trees on this area.

Because the trees were so carefully selected it is probable that the D.brevicomis infestation in them is considerably above the average. This is noticeable in the figures on emergence from the unexposed samples (Table 1), which are abnormally high.

The selected trees ranged from 20 inches to 44 inches in diameter breast high and from 75 to 110 feet in height. They were located on a variety of exposures, with slopes varying from 5 to 20 per cent. The amount of shade varied from none to 35 per cent. Four of the trees were felled flat on the ground, and the others were clear of the ground by from 2 to 20 inches. A summary of the data on the 12 trees is found in Table 1.

Methods

As previously stated, the general plan of treatment is simply to fell the infested tree in such a way as to give it the greatest possible amount of exposure to direct sunlight and then to trim off all branches, leaving the trunk fully exposed. Two of the trees studied in 1930 were also turned half around after being left exposed in one position for about a week.

Two methods were used to determine the effect of exposure on the broods within the bark: 1.. Samples of bark from near the center of the exposed area were taken in the form of a strip two feet in width and completely encircling the trunk, and caged in the metal-cylinder type of cage described in the 1923 report (Person (2)). As the broods emerged they were collected, sorted and counted by species. By taking two of such samples, one at the time the tree is felled and one after a period of exposure, it is possible to determine approximately the effect of the exposure by comparing the emergence from the two samples. Each sample varies in area from 10 to 20 square feet, with the average about 15 square feet. It would have been desirable to cage a pair of samples from each quadrant of the log, but this would have required the use of

eight cages for each tree studied, and the equipment and time that would have been needed for this amount of detail were not available. 2. The other method used served as a partial check on the first, and also gave a rough comparison of results between the top of the log and the log as a whole. This method consisted of brood counts, both before and after exposure, on sample areas of one square foot each. The samples were carefully shaved up and counts made to determine the abundance of each stage of the different insects. On the trees studied in 1928 and 1929 bark samples were taken from the top, bottom and both sides, both before and after exposure, and as a result the comparative effect of exposure on the different quadrants was pretty well worked out. In 1930 bark counts were made only on top of the log, because in the limited time available it would not have been possible to make counts from all four quadrants on the 12 trees studied.

It was planned to use still another method for determining the results of exposure in 1930 if groups of infested trees could have been found. In this method one or two trees in an infested group would be felled and studied according to the other methods just described. After emergence was completed emergence counts would be made from one or two of the trees of the group which had been left standing, for comparison with the emergence from the caged bark taken before and after exposure. If a number of trees of the same size and with the same type of infestation could be found in one group, so that the felled trees would be comparable with the trees left standing, this method would serve as a valuable check on our other methods.

Complete records were taken on each of the trees used. These records include a detailed description of the tree and its location, and the distribution, abundance and stage of the more important insects, which is obtained after the tree is felled. A diagram is used to show the distribution on the stem of the primary and secondary species for each tree.

Results and Discussion

The results of the 1930 season's work have been summarized in Table 1. The limitations imposed on the study by the great amount of detailed work required on each tree studied made it impossible to collect data from enough trees to allow statistical treatment of the different factors involved. Because of this it was necessary to consider each tree individually in relation to the factors affecting it in order to get as much as possible from the study. In this way it has been possible to give a fair indication of what might be expected under the conditions covered, though in many cases the results are by no means conclusive.

The results will be considered under a number of different headings, which include (1) a discussion of the brood reductions found and the effect of some of the more important factors on brood reduction, including the effect of (2) stage of brood, (3) amount of shade, (4) exposure and slope, (5) position of logs and (6) turning the logs.

Brood Reduction Resulting from Biological Control Treatment

A brood reduction of 45 per cent is indicated as a result of the exposure of the eight trees with advanced broods. Reduction in broods of newly-attacked trees could not be determined by the method used.

We find in Table 1 that the results from the caged-bark samples show an actual increase in the D.brevicomis broods following exposure in four of the trees, instead of the reduction which is to be expected. The reason for this is that the broods in these trees were so small at the time the first sample was caged that a high mortality occurred in the unexposed caged samples. Because of this the results from these four early brood trees are misleading and cannot be used in studying the effect of the exposure.

The following table gives the emergence for the unexposed and exposed caged bark for the eight trees with advanced broods and the brood reduction in per cent apparently resulting from the exposure. The results of bark counts made on the tops of eleven of the logs after exposure are also included to show the approximate mortality resulting from high temperatures. Since it is very difficult to find all the dead larvae after they have dried up, it is probable that the actual brood mortality is in many cases greater than indicated.

Brood Reduction Resulting from Exposure

Tree Number	Emergence from Caged Samples		Reduction in per cent	Bark Counts		
	Unexposed	Exposed		Living	Dead	% Killed
1 P.P.M.	---	---	---	87	42	30
2 "	152.0	31.6	79	9	145	94
3 "	---	---	---	110	5	3
4 "	132.6	98.8	46	11	204	95
6 "	74.0	62.6	29	120	26	17
7 "	98.6	90.7	8	49	40	45
8 "	118.0	70.6	40	2	91	98
2 Pi.Spr.	84.5	58.3	31	53	102	67
1 P.M.P.	45.6	18.6	59	70	6	8
10 Unt.MP.	---	---	---	126	10	8
404 T.Pt.	84.5	29.1	66	No bark count made		
Averages	105.0	56.3	46.5	82	58	47.4

*Not included because of brood mortality in cages, due to small stage of larvae.

**Not comparable with the reduction in per cent from the caged bark because the same trees are not included in both averages. If we average the results from the seven trees for which both the caged-bark and bark-count data are available, we find that the average reduction for the four quadrants is 42 per cent, whereas the average reduction for the top quadrant is 61 per cent. This is what would be expected, since the mortality from high temperatures would be much greater on top of the log than on any of the other quadrants.

This reduction in brood, which we assume is largely due to unfavorable conditions resulting from felling and exposure, while not very great compared with some of the results obtained from individual trees, is probably about what we could expect of this method in general practice under similar conditions. A reduction in the potential emergence of D.brevicomis from 105.0 per square foot to 56.5 per square foot, or 46.5 per cent, is far from complete control; and the determination of whether this method is more effective than the burning method depends on the value of the predators which are saved. This value is difficult to appraise; but on the basis of abundance of the predators and their potentialities as destroyers of D.brevicomis we can arrive at a fair approximation.

The following table gives the number of predators found on the eight trees for which the sacked-bark data are significant:

Abundance of Predators (per square foot)

Tree Number	Unexposed bark samples			Exposed bark samples		
	N.leconteï	T.v.c.*	Total	N.leconteï	T.v.c.	Total
3 P.P.M.	9.3	5.0	14.3	4.0	3.1	7.1
4 "	5.5	3.3	8.8	4.5	2.6	7.1
6 "	3.0	4.9	7.9	1.9	1.7	3.6
7 "	10.7	3.9	14.6	7.7	8.2	15.9
8 "	8.3	4.1	12.4	4.9	2.6	7.5
2 Pl.Spr.	15.9	7.1	23.0	6.1	3.3	9.4
1 PS.MP.	11.1	5.2	16.3	5.3	1.8	5.1
404 T. Mt.	15.1	5.7	20.8	1.8	6.7	8.5
Av.per sq.ft:	10-	5-	15-	4.3	3.8	8

*Temnochila virescens var. chlorodia

Although the number of predators found in both the exposed and unexposed samples have been included, this was done not to show a reduction in the number of predators resulting from the exposure, but the migration of the predators. We have found no evidence of increased mortality of the predators as a result of exposure in any of the trees studied except in the case of one tree used in 1928. In bark counts on the top of this log six dead and ten living clerid larvae were found. The D.brevicomis mortality in the same sample was nearly 100 per cent. This tree was exposed to full sunlight on a moderate southeast slope in a small opening in a close stand which allowed little air circulation, and the bark temperatures on top of the log must have been very high. Then too the tree was felled near noon on a very hot day, and it is probable that the bark temperature was raised so quickly that some of the clerids did not have time to escape. As this is the only case of mortality of predators due to exposure by this method on the 25 trees studied in 1928, 1929 and 1930, we assume that very few predators are killed by this method; and that the decrease in the average number of predators found before and after exposure--from 15 to 8 per square foot--is the result, principally at least, of migration either to other parts of the same log or to the ground to pupate. As the 1928 and 1929 studies indicate a migration from the top to the sides and bottom of exposed logs, and as mature clerid larvae have been found in numbers under stones and debris near the exposed logs, there is good support for this belief.

We may therefore assume that there is very little abnormal reduction of predators, and that the effective brood produced in the trees studied in 1930 would average close to 12 per square foot, allowing for some mortality between the larval and adult stages from natural causes. This figure is somewhat lower than the average for 1926 and 1927 on the Cascadel area of the Sierra National Forest, where the number of clerids alone averaged 12 per square foot. For an average year we could expect between 12 and 15 adult predators from one square foot of D.brevicomis-infested bark of the first summer generation.

Although we do not know how many bark beetles would be destroyed by one predator, we have some indication from controlled feeding experiments with both these predators. It was found that either predator would destroy on an average one D.brevicomis in two days. As the effective larval life of both predators would be at least three weeks and the adult life about two months, the potential consumption of either species would be approximately 40 D.brevicomis. The 12 or 15 predaceous adults from one square foot of bark might easily account for between 300 and 400 western pine beetle adults, in the adult stage alone. Looked at in this light it seems apparent that it would be better to do no control work of any kind than to do control work which resulted in the loss of these beneficial insects and that any method which reduced the D.brevicomis emergence, if only by 40 or 50 per cent, without injury to the predators, would be a great improvement on the burning method. But admitting that the exposure method would be preferable to the burning method on summer-generation trees, there is still some question as to the advisability of going to the expense of treating the infested trees for the sake of a 40 or 50 per cent reduction of the D.brevicomis emergence. It would probably be worth while on recreational areas and where timber values are particularly high, or where maintenance control or extermination was to be attempted, provided conditions were favorable for the use of this method.

To determine the value of this type of control it would be necessary to carry on one or more experimental control projects and make a careful study of the results. Even then the effectiveness would probably be in doubt unless the results were particularly striking. But since the burning method has proved of questionable value, any method which offers hope of an improvement should be worth trying.

The Relation Between Stage of Brood and Brood Reduction

Little relation between stage of brood and brood reduction was found in this study.

As the trees with advanced broods are most easily located, few of the trees with young broods have been used in these studies. However, in 1930 a few trees with broods in the small larval stage were selected for the purpose of comparing the effect of exposure on these young broods with the effect on more advanced broods. In the following table the 12 trees studied are arranged in order of size or age of brood, and the decrease in brood following exposure is given as a basis for comparison. The decrease in brood is shown as a percentage of the brood which emerged from a similar sample that was not exposed. Results from both the cored bark and the bark counts are included.

Table 8

Relation of Stage of Brood to Brood Reduction

Tree Number	Brood Before Exposure: Bark Counts	Brood Before Exposure: Emergence from Cages	Brood After Exposure: Bark Counts	Brood After Exposure: Emergence from Cages	Decrease in: Bark Counts	Per cent Caged Bark
N 8 P.P.M.	87 larvae 84 pupae	118.0	Living 2 Dead 91	70.8	09	40
N 7 "	92 larvae 60 pupae	99.6	Living 49 Dead 40	90.7	45	8
N 6 "	156 larvae 101 pupae	74.0	Living 130 Dead 26	52.8	17	29
N 4 "	190 larvae 72 pupae	182.6	Living 11 Dead 224	90.8	96	46
N 2	281 larvae 82 pupae	152.9	Living 9 Dead 145	31.6	94	79
N404 T.Mt.	330 larvae 32 pupae	84.5	No count	29.1	No count	66
N1 P.M.	113 larvae	45.4	Living 70 Dead 6	18.8	8	59
N 2 Flag Spr.	146 larvae	84.3	Living 53 Dead 109	53.3	67	31
N401 T.Mt.	203 larvae	33.3	No count	64.6	No count	95 Inc.in
N 3 P.P.M.	143 larvae	45.6	Living 110 Dead 3	78.0	3	70
N 1 "	192 larvae	26.3	Living 87 Dead 42	40.3	39	55
N 10 Ent.MP.	359 larvae	15.6	Living 126 Dead 10	106.5	8	664

In the table the trees are arranged according to the stage of brood at the time the tree was felled, with the most advanced broods first. The only exception to this rule is in the case of Tree N1-F3 MP. The brood in this tree when felled was in the egg and small-larval stage; but instead of peeling the bark for the unexposed cage sample, as was done with the other trees, a two-foot section was sawed out of the trunk and the whole section caged. This prevented the too-rapid drying out that caused the high mortality in the other unexposed samples with very young broods.

All the trees show a fair reduction of broods in the exposed samples except the last four listed--N 401, N-3, N-1 and N-10--all of which were infested with small larvae or eggs and larvae when felled. Since the broods could not increase as a result of the exposure, and since the bark counts on adjacent samples all show a brood reduction, it is evident that something happened to make the results misleading. The "something" is very probably a high mortality of the young broods in the unexposed sample, due to a too rapid drying out of the inner bark. Consequently the method used for comparing emergence from unexposed and exposed samples cannot be used when the brood is so small, at the time the first sample is taken, that any considerable part of the brood is still in or near enough to the inner bark to be adversely affected by the drying of this layer. In the case of small trees this could be avoided by cutting out and caging an entire section, as was done in the case of Tree N-1 F3.MP.

Because of this mortality of the young broods in the unexposed samples, the four trees mentioned will not be used in trying to determine the importance of various factors as affecting brood reduction. In the eight other trees the broods were in either the large larval or larval and pupal stages, and so were not appreciably affected by the drying of the inner bark. The D.brevicomis larvae usually leave the inner bark for the outer bark when about one-quarter grown, and when one-half grown they are probably deep enough in the outer bark to be unaffected by the condition of the inner bark.

The data presented in Table 2, while too limited to be conclusive, indicates that there is little relation between stage of brood and amount of brood reduction. If there is an optimum stage, it is apparently when the brood is mostly in the large larval stage with some pupae. The trees with the most advanced broods and those with the younger broods averaged slightly lower on brood reduction, though the tendency may not be significant. Since most of the trees "spotted" on a control project would have well-advanced broods, it is advantageous that the exposure method of control would be at least as effective on this stage as on the younger stages.

The results from the bark counts agree fairly well with the results from the caged bark except that no brood increase was shown. It is reasonable that results from the two sources should differ somewhat, not only because there is considerable variation in adjacent samples but also because the bark counts, which were all taken from the top of the log, would show principally the effect of high temperatures; whereas the caged samples from completely around the log would reflect more the effect of such factors as concentration of predators and unfavorable moisture conditions.

Relation Between Amount of Shade and Brood Reduction

It is evident that the amount of shade on the exposed logs would directly affect the bark temperature and consequently the mortality of the broods. The amount of shade cast on the logs was estimated and expressed in per cent, the time of day when the shade was cast being considered in estimating the importance of the shade; i.e., shade during the middle of the day would have a much higher value than shade earlier or later. The results are shown in the following table (Table 5), in which the trees are arranged according to the amount of shading:

Relation Between Amount of Shade and Brood Reduction

Tree Number	Shade in Per Cent	Brood Reduction in Per Cent			
		Caged Bark		Bark Counts	
#404 T.Mt.	0	56		no count	
2 P.P.M.	5	79	63	94	95
4 "	5	46		95	
2 Flag Springs	10	31		87	
1 P.P.M.	10	*	36	30	68
8 "	10	40		98	
1 "	15	59		8	
6 P.P.M.	20	28		17	
5 "	25	*		3	
7 "	35	8		45	
10 Mt. MF	50	*		8	

*Brood too small to rear in cages because of drying of inner bark

The results are shown graphically in Figure 8.

As expected, there is evidently fairly close correlation between amount of shade and brood reduction. Because of the effect of other factors, such as exposure and slope, bark thickness and distance off ground, it is natural that there should be some irregularities.

There appears to be a fairly definite difference between the trees with less than 15% shade and those with more than 15% shade. The average brood reduction for trees with less than 15% shade is 52 per cent for the caged bark and 79 per cent for the bark counts; whereas the trees with 15% shade or more show a brood reduction of only 32 per cent and 16 per cent respectively. It is also evident that the amount of shade affects the top of the log much more than the log as a whole; this is shown by the fact that the brood mortality on top of the logs with the least shade is 52 per cent greater than on the entire log, and the mortality on top of the logs with the most shade is 30 per cent less than the mortality on the entire log.

Evidently between 15 and 20 per cent shade is sufficient to prevent temperatures fatal to D.brevicomis broods on the tops of exposed logs.

Effect of Exposure and Slope on Brood Mortality

No consistent relation between exposure and slope and brood reduction was found on the trees studied, probably because the slopes represented were not steep enough to interfere with brood reduction.

The twelve trees used in the 1930 studies were situated so as to represent a variety of the slopes and exposures found on the Western Modoc area. The results are summarized in the following table, in which the trees are arranged according to the favorableness of the exposure and slope for causing high bark temperatures on the tops of the logs. The trees with the least favorable exposure for securing brood mortality are listed first. Both exposure and slope were averaged together as one factor, assuming that the greater the slope the less favorable for brood mortality on unfavorable exposures (N, NE and NW) and the more favorable for brood mortality on favorable exposures (E. SE and S).

Table 4

Effect of Exposure and Slope on Brood Mortality

Tree Number	Exposure and Slope	Brood Reduction in Per Cent: Caged Bark	Bark Counts (top of log)
N 8 P.P.M.	G 5%	76	94
7 "	SE 5%	8	45
6 "	SE 35%	89	17
2 Flag Spr.	N 10%	31	67
1 P.P.M.	N 5%	59	8
5 P.P.M.	NE 8%	40	98
10 P.P.M.	NE 45%	—	8
3 P.P.M.	NW 8%	—	3
1 "	NW 5%	—	89
4 "	N 8%	46	95
404 "	N 20%	68	(No count)

The above data are shown graphically in Figure 5.

These data show very little effect from differences in exposure and slope within the range studied. Evidently a moderate slope has little relation to the effectiveness of the method, regardless of the exposure. A south exposure with a five per cent slope resulted in little more brood mortality than a north or northwest exposure with the same slope. Even the most unfavorable exposure--Tree N-404, with a north exposure and a 20 per cent slope--gave almost as high a mortality as any of the other exposures and slopes.

Apparently, within the range of conditions covered, there is little relation between exposure and slope and brood reduction. If this is found to be generally true it will mean that most of the slopes and exposures represented on many of the pure yellow pine areas of northern California and southern Oregon are not unfavorable for the use of this method.

It is unfortunate that steeper slopes were not represented, so that a comparison between steep unfavorable slopes and moderate or favorable slopes could have been demonstrated.

Relation Between Log Position and Brood Reduction

Since logs lying on the ground permit less air circulation than logs above the ground, it would be expected that bark temperatures and consequently brood mortality would be greater on logs exposed flat on the ground. In the following table (Table 5) the brood reduction in logs left flat on the ground is compared with brood reduction in logs which were clear of the ground. (See Graham (5) for more complete treatment.)

Table 5

Brood Reduction in Logs Lying Flat on Ground Compared with Brood Reduction in Logs Above Ground

Tree Number	Brood Reduction in Per Cent	
	Caged Bark	Bark Counts
Logs Exposed Flat on Ground		
N 1 P.P.M.	—	39
2 "	79	84
3 "	—	5
4 S.P.M.	46	95
8 "	40	98
Average	55%	66%
Logs Exposed 3" to 18" Off Ground		
N 6 P.P.M.	89	17
7 "	8	45
2 Fl.Spr.	31	87
1 PSM	59	8
10 SSP	—	8
404 T. Mt.	66	—
Average	59%	28%

It is not possible to tell just how important this factor is because there are so many other factors that influence the results. But since trees flat on the ground would permit less air circulation, higher bark temperatures and consequently greater brood mortality would be expected. Where possible, therefore, trees felled for control by this method should be felled flat on the ground.

Effect on Brood Reduction of Turning the Logs

It is evident from the 1928 and 1929 studies (see also Table 1) that the highest mortality of D.brevicomis broods occurs on the tops of the exposed logs. Because of this it was thought that the average mortality for all four quadrants could be increased by turning the logs half around after about one week of exposure in the first position. This method was tried with two of the trees studied; but because of an unfortunate selection of trees, as well as slightly subnormal temperatures after the logs were turned, the results are not very significant.

Two of the smallest trees studied were used, as the larger trees would have been difficult to turn without horses or special tools, which were not available. Both trees were in moderately unfavorable situations in regard to shade, exposure and slope. Tree N-2, Flag Spring, had 10 per cent shade and was on a west exposure, 10 per cent slope; Tree N-1, Forest Service marking plot, had 15 per cent shade and was on a west exposure, 5 per cent slope. Both trees were felled so as to be clear of the ground.

In spite of the fact that these trees were turned, the brood reduction is only about average and there is no evidence that the turning of the logs in any way affected the brood mortality. Evidently the combination of 10 to 15 per cent shade and moderately unfavorable exposure and slope neutralized any good effects that might, under more favorable circumstances, have resulted from turning the logs.

Another factor that probably affected the results is the air temperature during the period of exposure. The temperatures after the logs were turned were slightly below the normal maximum for that time of the year (Table 1). This is particularly noticeable in the results from Tree N-1. On this tree only eight per cent of the brood on top of the log was killed after turning, whereas the average brood reduction for the entire log was 89 per cent. This shows that although the mortality from the first exposure (on top of the log) was probably high, the mortality on top of the log after it was turned was almost negligible.

In spite of the inconclusive results it seems obvious that if a log is favorably exposed it would be advantageous to turn it, since a mortality of over 90 per cent is not unusual on top of a log, while a [illegible] per cent brood reduction is the maximum recorded for the log as a whole. It would be a waste of time to turn logs which are not exposed so that a high percentage of the brood on the top is killed.

The other factors considered--viz., bark thickness, abundance of predators, direction felled and maximum temperatures during the period of exposure--showed no definite effect on brood reduction. This does not mean that they are of no importance, but rather that their influence is obscured by the more important factors as well as by the lack of sufficient data. It seems probable that the thinner-barked trees, with the greatest number of predators, which were exposed in a north and south direction during periods of highest air temperature, would have the highest percentage of brood reduction, other factors being equal. (Graham (8))

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the past three seasons' work a number of conclusions have been reached. The data bearing on many of the points covered is obviously inadequate, but we believe that where the results have been consistent during the three seasons and are in agreement with the results of other workers, the conclusions are justified.

1. The burning method of control of D.brevicomis is unsatisfactory for work on the summer generation, not only because of the fire hazard but because the beneficial predators, which are most abundant in the summer-generation trees, are destroyed by this method.

The sun-curing method, although more satisfactory for summer work than the burning method, also causes fairly high mortality among the predators.

2. The biological method of control may be used to advantage under favorable circumstances where summer control is desirable.

Using this method, in which infested trees are felled in open situations and trimmed so as to leave the trunk exposed to direct sunlight, the following results may be expected:

A. In an area similar to the northwestern part of the Modoc National Forest, an average reduction of between 40 and 50 per cent of the D.brevicomis broods results without apparent injury to the beneficial predators;

B. On the tops of the most favorably exposed logs a mortality of over 90 per cent of the broods occurs, also without injury to the predators;

C. There is evidently higher mortality on the sides and bottom of a felled, exposed log than on an infested tree left standing. This may be due to the concentration of the predators driven from the top of the log by high temperatures and by temperature and moisture conditions unfavorable for brood development. Bark temperatures are found on the west sides of certain logs that are high enough to cause some direct killing of D.brevicomis broods;

D. The principal predators, E.lecontei and T.virescens chlorídia, are not only able to escape from high temperatures because of their motility, but they are also apparently able to withstand higher bark temperatures than D.brevicomis.

3. The biological method has the following limitations:

A. It is applicable only to summer work, both because high temperatures are necessary and because overwintering trees usually do not have enough predators to make the method worth while;

B. It would be effective only in fairly open stands, where a fair percentage of the treated trees could be exposed to full sunlight. Little direct killing of the broods from high temperature would occur in trees with more than 15 or 20 per cent shade;

C. The topography should be either moderately level or with few steep northerly exposures. The method is apparently effective if the unfavorable exposures do not have slopes of over 15 or 20 per cent.

It is suggested that if this work is to be continued an experimental control project is the next logical step. The following suggestions would be applicable to such a project:

1. Trees should be felled so as to give the greatest possible exposure to direct sunlight. It might prove practical, where horses or tractors are available, to skid some of the trees out into the open, so as to give them a more favorable exposure. The same equipment could be used for turning the logs, if found to be advisable;

2. Trees should be felled flat on the ground to reduce air movement, which lowers the temperature;

3. Fell trees in a north and south direction, as this will give the greatest bark area of high temperature on the top of the log;

4. Turn the logs half around after a high brood mortality has been obtained on top of the log;

5. Use the sun-curing method on trees which cannot be exposed so as to give effective control by the biological method.

It is difficult to compare the effectiveness of this method with the burning or other methods which kill a much higher percentage of the D.brevicomis broods but all the predators as well. On the basis of limited feeding experiments with predators, however, it is probable that the average number of predators saved by the biological control method would easily destroy many times the number of bark beetles which were allowed to emerge. The average number of predators emerging was about 15 per square foot, each of which is theoretically capable of destroying 30 bark beetles in its 30 days of adult existence, or a total of 450 beetles for the predators which are saved from one square foot of bark. If we discount these figures 90 per cent, the biological method would still have a safe margin over any method of control that destroyed these predators, even though 95 per cent of the bark beetles were killed.

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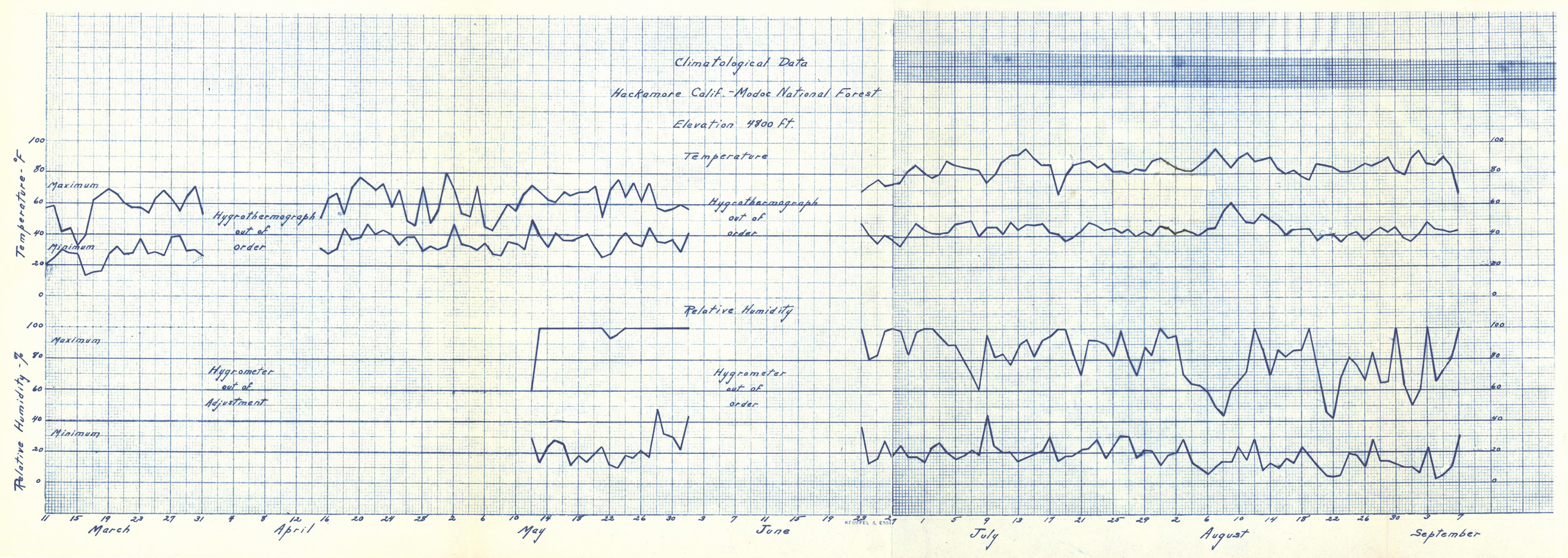
Table 1

Summary of Experimental Data by Trees

Tree No.	Location	Diam. In.	Ht. Ft.	Bark Area Caged sq.ft Unexp.	Bark Area Caged sq.ft Exp.	Date Felled	No. Days Exp.	Bark Thickness Inches	Shade %	Exp.	Slope %	Dir. Felled	Distance above Ground Inches	Ingrowth from Caged Bark: D. brevicomis Unexp.	D. brevicomis Exp.	D. brevicomis Ins.	D. brevicomis Dead	E. leconteii Unexp.	E. leconteii Exp.	T. v.c. Unexp.	T. v.c. Exp.	Sq.Ft. Sample Bark Counts, Tops of Logs: D. brevicomis Before Ex.	D. brevicomis After Ex.	D. brevicomis Dead	E. leconteii Before Ex.	E. leconteii After Ex.	T. v.c. Before Ex.	T. v.c. After Ex.
						1930																192 L.	Liv. 67					
N---1	P.P.E.	28	100	20.2	18.4	7/8	21	1/2	10	SW	5	N	0	26.3	40.8	55		4.9	3.8	6.3	2.5	0- .5	Dead 42	39	too small to count	1	--	2
																						282 L.	Liv. 9					
N---2	"	44	110	18.1	19.1	7/15	13	2	5	S	5	NNE	0	152.0	51.6	79		9.3	4.0	5.0	3.1	62 P.	Dead 148	94	5	6	3	1
																						143 L.	Liv. 110					
N---3	"	32	95	14.3	15.6	7/15	22	1	25	Ns	5	E	0	43.6	78.0	79		6.3	5.5	4.5	5.1		Dead 3	3			1	4
																						190 L.	Liv. 11					
N---4	"	40	110	17.8	20.0	7/17	11	1	5	N	5	SW	0	182.6	98.8		46	5.5	4.5	3.3	2.6	72 P.	Dead 124	95	0	3	8	5
																						158 L.	Liv. 130					
N---6	"	31	75	10.0	10.3	7/18	13		20	SE	5	SW	18	74.0	58.8		29	3.8	1.9	4.9	1.7	101 P.	Dead 26	17	2	0	7	0
																						92 L.	Liv. 49					
N---7	"	34	110	18.0	18.4	7/22	13	1	35	SE	5	WSW	2-5	98.6	90.7		8	10.7	7.7	5.9	8.2	40 P.	Dead 40	45	1	0	5	4
																						87 L.	Liv. 8			(dead)		
N---9	"	36	95	15.6	14.0	7/23	12	1	10	NE	2	ENE	0	118.0	78.8		40	8.3	4.9	4.1	2.6	64 L.	Dead 91	98	0	1	3	1
Trnd.7/23																						146 L.	Liv. 53					
N---8	Flag Spr.	32	105	14.0	14.0	7/22	15	1	10	W	10	N	3-6	84.3	88.3		31	15.9	8.1	7.1	3.3	.5-1.	Dead 109	67	0	8	2	1
Trnd.7/22	F.S.																					115 L.	Liv. 70					
N---1	F.S. Exp. Ext.	20	100	8.8	8.8	7/9	23		15	W	5	WNW	6	45.6	18.8		59	11.1	5.3	9.2	1.8	0-0.5	Dead 6	8	0	6	1	1
																						385 L.	Liv. 126					
N---10	Exp. Plot	26	90	15.3	13.5	7/22	15	1	30	NW	4	ESE	18-20	13.6	106.5	684		15.0	5.8	8.6	8.8	0-0.5	Dead 10	8	1	4	3	3
																						293 L.						
N-401	Tim. St.	34	90	10.5	11.5	7/10	21	1	80	NNW	5	NNW	2-6	33.2	64.8	95		5.5	3.9	8.3	5.6	0-1.0			0	0	1	0
																						330 L.						
N-404	"	32	100	14.2	14.2	7/11	18	1	0	S	20	W	6	84.5	29.1		66	15.1	1.8	5.7	6.7	38 P.			6	0	4	0
																						2705 L.	Liv. 627					
Totals		372		172.8	170.6		197		208		74			956.3	740.6		358	105.6	50.6	88.9	50.0		Dead 696	474	18	88	32	22
																							Liv. 88					
Averages		31		14.4	14.2		16.4		17.0		6.2			(80.0	61.7		30)	9.8	4.2	5.0	4.2	225	Dead 58	47.4	1.1	2.3	2.7	1.8
														105.0	56.3			48.5										

*Results from 8 selected trees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Hackamore Calif. - Modoc National Forest
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Temperature
Temperature - °F
Maximum
Minimum
Hygrothermograph out of order
Hygrothermograph out of order
Relative Humidity
Relative Humidity - %
Maximum
Minimum
Hygrometer out of Adjustment
Hygrometer out of order
100
80
60
40
20
0
11 15 19 23 27 31 4 8 12 16 20 24 28 2 6 10 14 18 22 26 30 3 7 11 15 19 23 27 1 5 9 13 17 21 25 29 2 6 10 14 18 22 26 30 3 7
March
April
May
June
July
August
September
KEUFFEL & ESSER

Figure 2

Relation Between Amount of Shade and Brood Reduction

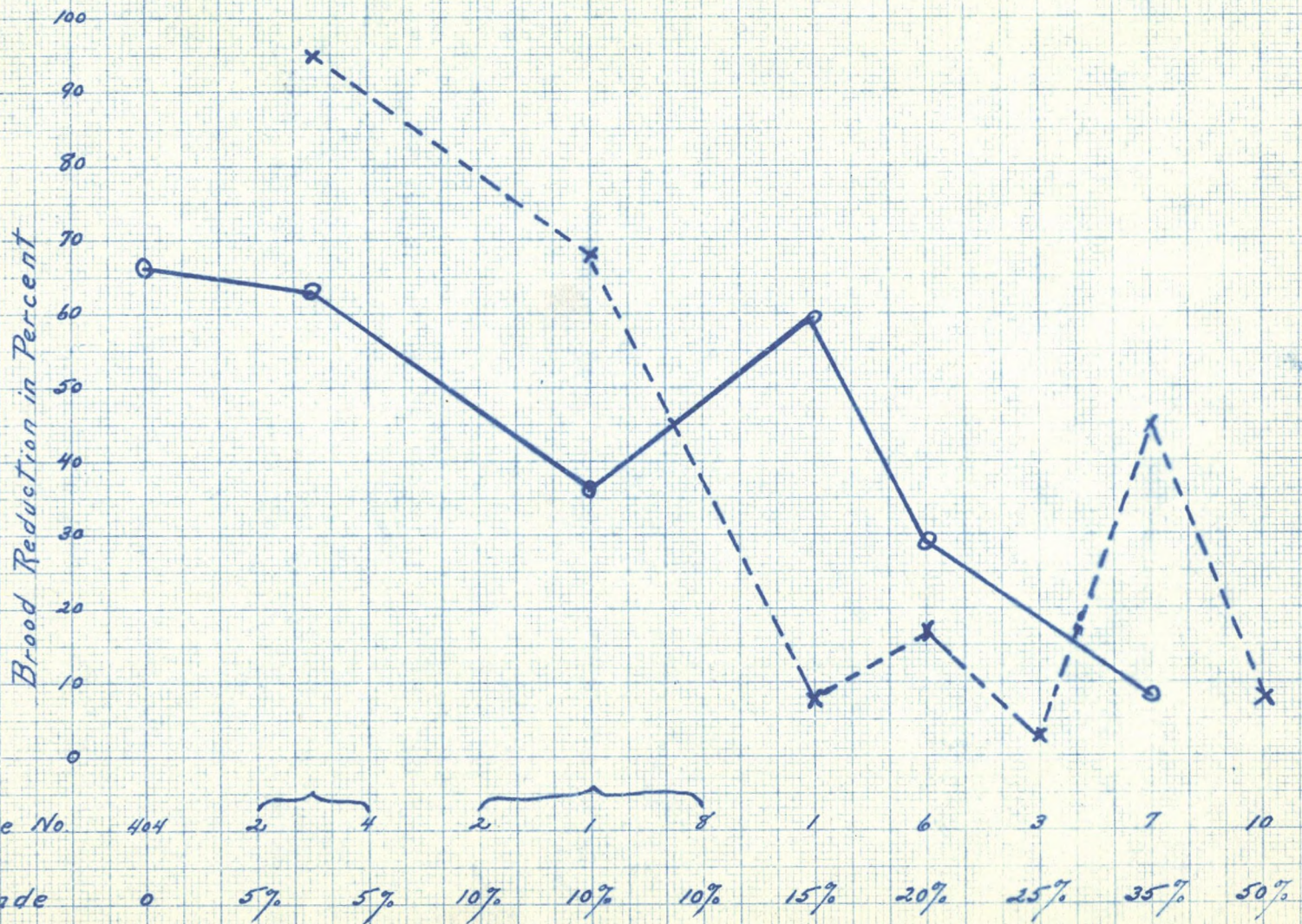

Figure 3

Relation Between Exposure and Slope and Brood Reduction

Tree No.	2	7	6	2	1	8	10	3	1	4	404
Exposure	S	SE	SE	Flaq Sp. W	FSM. W	NE	EMP NW	NW	NW	N	N
Slope	5%	5%	3%	10%	5%	2%	4%	5%	5%	5%	20%